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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

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DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

July, 1970

Interim Report
No. M & R 632101

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

ERODIBILITY OF SLOPES
(Phase I)

Travis Smith
Principal Investigator

Raymond Forsyth and Bennett Squires
Co-Investigators

Assisted by
John Campbell

70-04

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

"In cooperation with the U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads."

70-04

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KEY WORDS: Soils, erosion, dispersion ratio, surface aggregation ratio, permeability, slope, rainfall intensity, infiltration rate, cohesion, moisture content, soil loss.

I. INTRODUCTION

In the work plan submitted to the Bureau of Public Roads in July, 1969, for the above project, the objective, background and scope were presented as follows:

OBJECTIVE

The objective of this research project is to develop criteria to be used to predict the potential erodibility of highway cut and fill slopes, taking into account soil characteristics, geologic characteristics, local precipitation patterns, and cut and fill slope geometry.

BACKGROUND

In the design of cut and fill slopes, stability has historically been the primary concern. Slope recommendations are made based upon geological information or by recognized methods of analysis using soil strength parameters developed from laboratory tests. Erosion potential, a factor which should be taken into consideration during the design stage of a highway, is not at present given consideration on a systematic basis due to the lack of standard procedures for evaluation of this problem.

SCOPE

The scope of this project will be limited to developing the ability to evaluate potential slope erosion problems as stated in the objective. No direct attempt will be made to develop corrective treatments for various soil types, although the data collected will provide worthwhile information for future studies in this area. It appears that a logical starting point in the study of slope erosion is to categorize erodibility by some standard yardstick.

Efforts to predict erodibility from physical, chemical, and geologic soil characteristics have been reported on extensively. A search of available literature will therefore provide the basic precepts on which this project will be founded. Supplemental work will involve sampling and testing soils from numerous locations throughout the State, gathering additional pertinent information on field conditions, and performing a statistical analysis of factors relating to slope erosion.

It was further proposed in the work plan that the project be carried out in three phases delineated as follows:

Phase I

The initial step of this project will be an extensive search of the current literature on slope erosion. From our current knowledge of the problem and the results of the literature search the preliminary precepts for the laboratory testing program will be developed.

Preliminary field surveys and samplings will be conducted on the selected number of existing slopes. Tests will be conducted on the materials taken from these slopes to determine the characteristics which may lead to erosion. A statistical analysis will be conducted to determine the correlation between the survey and test data and the current state of erosion. From this analysis an interim report will be issued describing a proposed method of erosion prediction.

Phase II

From the procedures developed in Phase I of this project an extensive field survey and sampling will be made on approximately 100 sites throughout the State. Although all the pertinent characteristics are not currently known, the more obvious parameters that will be recorded and evaluated are (a) size, location, and erosion history, (b) rainfall data - total or average per month and short term intensity, (c) slope ratio, (d) height slope, (e) depth of gullies at 15-foot intervals, (f) age of slope, (g) geologic conditions. Laboratory tests to be performed are (a) gradation, (b) plasticity, (c) other tests as developed during Phase I of the project.

Phase III

Phase III will consist of the analysis and reporting of the prior phases and will result in a recommendation guideline to determine erosion potentials in highway cut and fill slopes.

Approval of the project and authorization for Phase I in the Fiscal Year 1969-70 to the amount of $5000 was granted effective December 10, 1969, with a proviso that authorization of successive phases of the project would hinge on attainment of Phase I objectives.

It was proposed to conduct Phase I activities in two steps, the first being the development of a laboratory testing program which would offer a reasonably good chance of achieving the stated objectives of the project, to be based upon an extensive search of current literature on slope erosion. The second, a preliminary field survey and sampling, would be conducted on existing slopes with tests to determine the characteristics which may lead to erosion. A proposed method of erosion prediction would then be formulated based on correlations between the survey and test data and the current state of erosion observed in the field.

The literature search objectives entailed a considerably greater expenditure of the Phase I allocation than anticipated. As a consequence it proved necessary to readjust the project alignment and scope commensurate with funds available. A modified program of soil testing in the laboratory was substituted for the field activities originally contemplated. It had become evident early in this investigation that the soil erodibility factors sought must be based on evaluation of data from various test procedures. Furtherance of the project required at this point development of skill in performing the appropriate tests and a degree of expertise in interpreting the data. It was reasoned that such indoctrination might be successfully and economically implemented through test trials conducted on suitable surplus samples on hand. Accordingly, several test series were conducted to determine those soil properties identified in the literature as erosion factors.

This report presents the results of Phase I of the project as modified including a summarization of the literature search, and a description of the test procedures utilized with analyses of the data resulting.

In accordance with the letter of December 10, 1969, from Mr. Donald E. Trull, Bureau of Public Roads Division Engineer, to John A. Legarra, State Highway Engineer, work on Phases II and III of the project will be deferred pending review and approval of this report by the Bureau of Public Roads.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of California or the Bureau of Public Roads.

II. CONCLUSIONS AND RECOMMENDATIONS

The results of a comprehensive literature search and a limited number of laboratory tests support the following conclusions:

1. It appears probable that technology developed through research by the Department of Agriculture and other agencies for the evaluation of potential erodibility of soils can be adapted to provide a method for predicting the erodibility of highway cut and fill slopes.

2. Two prime factors in evaluations of soil erodibility are the dispersion ratio and the surface-aggregation ratio. In the opinion of Dr. Kandiah Arulanandan, of the University of California, Davis, the cohesive strength and permeability of a soil exert important influences on the erosion process and any valid assessment of soil erodibility must give weight to these factors as well.

3. The procurement and processing of soil samples for determination of erodibility factors should be conducted with care to maintain the integrity of the soil structure. Undisturbed samples, as well as bulk samples, should be removed from existing slopes for testing. At the time of sampling, full information with regard to such data as slope geometry and the current state of erosion

should be recorded. Sample preparation prior to tests should be gentle and in full accordance with recommended procedures.

4. Observations of induced erosion on existing slopes would provide useful data in evaluation of erosive tendencies. It is anticipated that experimental procedures will be initiated to implement such observations. Under consideration is a plan to use a truck-mounted water tank so equipped as to permit application of water spray under controlled conditions. The erosion caused by the simulated rainfall will be correlated with dispersion and surface-aggregation ratios determined in laboratory tests. Samples taken adjacent to the sprayed areas will be processed and tested to determine erodibility factors in accordance with procedures followed in Phase I of this program.

Based upon the results of Phase I, the following work plan for Phase II is recommended. An extensive field survey and sampling will be made throughout the State. Parameters that will be introduced include: (a) site location and erosion history, (b) rainfall data, (c) slope ratio, (d) height of slope, (e) depth of gullies, (f) age of slope, (g) geologic conditions.

Laboratory tests will be performed as developed during Phase I of the project and a statistical evaluation in the form of a multiple regression analysis of all factors related to slope erosion will be made.

III. SURVEY OF LITERATURE

Erosion can be defined as the detachment and transportation of soils by natural forces. Some authorities have divided this phenomenon into two types: rock or geologic erosion, the orderly creation of soil under the impact of natural influences such as climate, vegetation, micro-organisms, and chemical and physical activities; and soil erosion, an accelerated process of soil removal brought about by human interference with the normal equilibrium between soil building and soil removal. The variable factors affecting soil erosion were summarized by Baver[7] in the descriptive equation:

$$E = f(C, T, V, S, H)$$

where C = climate, T = topography, V = vegetation, and S = soils.

The fifth variable, H, the human factor, is included since man now plays an ever increasing role in accelerating the erosion process and will presumably play an equally important part in controlling erosion. Water erosion is due to the dispersive action and transporting power of water as it descends as rain and leaves the land in the form of runoff. The dispersing action and transporting power of water are determined by, first, the dispersive effects of falling raindrops and the amount and velocity of runoff and, second, the resistance of the soil to dispersion and movement.

The severity of erosion depends on the amount of runoff and its velocity. Various soils will erode differently dependent on the resistance that is offered to dispersion and movement. There are certain storms that will make the most ideal soil erode if it is not protected by vegetation. The degree of soil movement will be proportional to the ease with which the soil can be dispersed.

Aggregation, volume changes and hydration are important factors affecting erosion, once dispersion due to raindrops and runoff occurs. The investigations of Diseker and Yoder (1936) and Neal (1937) (15) indicated that there are two structural conditions of the soil surface that determine the amount of erosion. These are: (1) A slaking action occurs at the immediate surface with the first increment of rainfall when the soil is dry and compact resulting in a high density of runoff. As the rain continues, after this thin layer of loose soil has been removed, a wet compact surface is produced which decreases the density of runoff in spite of a greater total runoff. The resistance of the wet layer to erosion apparently increases with the clay content. (2) If the soil is loose and granular there is little erosion at the beginning of the storm due to the high infiltration capacity. However, when the rainfall intensity exceeds the infiltration capacity the soil loss is high. If the cohesive fraction is lacking, the soil erodes to the bottom of the loosened layer. Here, granulation expedites rather than hinders erosion. Infiltration is defined as the process involved when water soaks into soil through the immediate surface. It is not synonymous with percolation which is water movement through the soil profile. The infiltration capacity of a soil is equal to the rate at which water can enter it. The maximum infiltration capacity of a soil is rarely equivalent to the percolation rate or transmission capacity since the amount of water percolating through a soil profile is determined by the permeability of the least pervious horizon. When rainfall intensity exceeds infiltration capacity, runoff occurs.

While an open soil surface increases infiltration, a compact surface deters it and promotes high runoff. The two major factors in determining the runoff from any given storm are the structural properties of the immediate surface and the moisture content of the soil profile. The soil-moisture content at the onset of a storm has an important effect on infiltration rates and runoff. Baver observed in 1956[7] that field studies of factors influencing runoff and erosion demonstrated soil moisture to be a major factor in determining runoff from slopes with different exposures. The studies indicated that runoff was greater according to the following series: north>west>east>south. The moisture content of the soil increased in the same order.

Climatic influences are manifested either in the form of reduced or increased infiltration capacities. Torrential rainfall distribution at the time when the soil is not adequately protected causes rapid compaction of the surface and clogging of the pores. The infiltration rate is quickly reduced under the beating action of the rain and runoff is greatly increased. Freezing of the soil surface and upper soil layers retards infiltration and contributes to high velocity runoff and to the severity of winter floods.

Prolonged dry spells generally increase infiltration capacity due to cracking and checking of the soil surface. This fact can be significant in heavy soils that normally possess low infiltration capacities. The splash effect of raindrops on soil surfaces as a factor in soil erosion have been the subject of involved studies. When the soil is adequately protected by vegetation, the raindrop impact is softened and little or no effect ensues; however, raindrop impact and "splash effect" on exposed soils results in processes which can be a major factor in infiltration and runoff rates. The raindrop splash on bare ground throws fine soil particles into suspension. When conditions are such that the water is readily absorbed by the soil, small particles are carried downward by infiltration. By a process of straining out, these particles plug the soil pores, sealing off further penetration of water. During early rains this action often traps air in the surface horizons which augments resistance to infiltration. Continued rain will cause puddling, a liquéfaction of the soil, and heavy erosion when runoff starts. It should be noted that even sandy soils may become impermeable because of crust formation as a result of raindrop action.

Slope characteristics are important factors in determining the amount of runoff and erosion. Of the two essential characteristics of slope, degree and length, the former is usually the more important from the standpoint of the severity of erosion. Baver[7] has demonstrated that on slopes below about 10 percent the amount of erosion more than doubles as the degree of slope increases twofold. Losses from steeper slopes do not increase in the same proportion as losses from more gentle slopes. Most of the experimental data indicated that the degree of slope has little effect upon the percentage of runoff. The data of Neal[15] in 1937 showed that erosion varied as the 0.7 power of the percentage slope. Runoff and erosion increase with the length of slope under rains of high intensity while the reverse is true under rains of low intensity. Soil properties also play an important role in determining the type of runoff and erosion with varying slope conditions.

A good vegetative cover offsets the effects of climate, topography and soil on erosion. The major effects of vegetation may be classified into five distinct categories.[7] They are (a) the interception of rainfall, (b) the decreasing of runoff velocity and cutting action, (c) increased granulation and porosity by root effects, (d) biological activities associated with vegetative growth and its effect on porosity and (e) transportation of water leading to drying out of the soil. The soil factor in erosion cannot be separated from the vegetation factor; they are interdependent. A vegetative cover helps to determine the soils resistance to dispersion and transportation.

In 1930, H. E. Middleton,[14] a soil physicist, published the results of a study of the properties of soils which influence soil erosion. He sought to find relationships between erosivity and the physical and chemical characteristics of soil types with a view to obtaining indices of soil erodibility. His method consisted of correlating results of laboratory soil analysis with erosion as determined in the field.

Three soil qualities were found by Middleton to have a pronounced correlation with erosional behavior as observed in the field:

1. Dispersion ratio.

2. Ratio of colloid percent(1) to moisture equivalence(2).

3. Erosion ratio.

He found that probably the most significant single quality inherent in a soil with respect to its erosion potential is its dispersion ratio or the readiness with which individual particles go into suspension in water. The dispersion ratio was obtained by dividing the amount of silt and clay that was easily suspended by shaking soil in pure water by the total quantity of silt and clay present in the soil. The greater the ratio the more easily the soil could be dispersed, or, the dispersion ratio decreased as the resistance to erosion increased.

The second quality determined by Middleton, the colloid-moisture equivalent ratio, is a function of the ease of percolation and absorptive power of the soil. Permeability was considered to increase with this ratio.

On the theoretical assumption that erosion should increase directly with the dispersion ratio and inversely with the colloid-moisture equivalent ratio, Middleton developed the third of his criteria, the erosion ratio.

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(1) Colloid content, extracted by water-vapor absorption method.

(2) The amount of moisture (expressed as a percentage of the weight of oven dried soil) retained by soils which have been saturated in water and then subjected to centrifuging at a force equal to 1000 times the force of gravity for 1 hour.

The erosion ratio is found by dividing the established dispersion ratio by the indicated colloid-moisture equivalent ratio. The erosion ratio combines the relations of the soil towards water in such manner that a low value of the ratio is indicative of high resistance to erosion. The erosion ratio distinguishes the erosive from nonerosive soils in the same order as the dispersion ratio but the differentiation is more marked. The erosion ratios appear to express more satisfactorily the difference between soils. Middleton found satisfactory qualitative correlations between the erosion ratio and the erodibility of most soils investigated. Neither dispersion nor erosion ratios are to be regarded as quantitative expressions of relative erodibility.

Middleton found that none of the chemical properties studied could be used to differentiate between erodible and nonerodible soils. He expressed, however, a belief that the silica-sesquioxide ratio might have an important bearing on soil erosion. The silica-sesquioxide ratio is defined as the molecular ratio of the silica to the combined alumina and iron oxide present in the colloid.

Although the early work of Middleton was somewhat limited in scope, he achieved a major breakthrough in the understanding of the mechanics of erosion. His concepts and techniques have been utilized by others on an expanded scale.

In 1932, Baver[7] expressed a belief that erodibility varies directly with the ease of dispersion and inversely with permeability, aggregation, and particle size. This concept is summarized in the descriptive equation:

$$E = K\frac{D}{AP_p}$$

Where K refers to a proportionality constant, (involving the factors: climate, topography, vegetation, soils and the human factor), D is an index of the ease of dispersion, A is an expression of the infiltration capacity of the soil surface, P characterizes the permeability of the soil profile, and p denotes the size of the soil particles. This equation emphasized the need for evaluating both the dispersity of the soil particles in the surface layers and the pore-space relationships of all layers of the profile before an approximate picture of the erodibility of a soil can be had. Subsequent studies by others (Lutz 1934 and Diseker and Yoder 1936) confirmed that ease of dispersion and permeability were the foremost factors in erodibility.[5] They concluded that one of the principal differences between erodible and nonerodible soils is the degree of aggregation of the finer mechanical separates into large, stable granules. They found that eroded particles were aggregates rather than mechanical separates, showing the importance of knowing not only the amount but also the size distribution of the soil aggregates. In 1936, Yoder[19] devised a method of determining the amount of water-stable aggregates in soils by wet sieve analysis which proved to correlate well with erodibility as observed in the field.

In 1951, Anderson[2] tested the relationship of several physical characteristics of soil to measured suspended-sediment discharge from watersheds and demonstrated the usefulness of erodibility indices. He recommended Middleton's dispersion ratio because of its simplicity and usefulness. Anderson, in 1954, hypothesized that erodibility of a soil depended on the surface of the soil requiring binding, fine sand size and larger, versus the binding quality of the clays.[1] He introduced a new index of soil erodibility, the surface aggregation ratio. This index is defined as the amount of surface in cm^2/g on particles larger than silt (larger than 50 microns in diameter) divided by the aggregated silt and clay, or the amount of surface requiring binding to the amount of binding clay present in the soil. The surface-aggregation ratio was found to be closely correlated to suspended-sediment discharge from 33 watersheds when used in a multiple regression analysis. The relationships obtained indicated relative erodibility of the soils developed on different geologic rock types and permitted a prediction of sediment yield to be expected with changes in selected variables.

In 1961, Wallis and Stevan studied 20 northwestern California soils to determine the relation of the erosion ratios described above to measurements of the soils' chemical base status. They found a high degree of correlation between the dispersion ratio, the surface aggregation ratio, and the Ca+Mg absorbed on the soil clays.[5]

In 1961, Andre and Anderson[5] presented results of a study of the variation of soil erodibility with geology, geographic zone, elevation and vegetation type in northern California wildlands. They analyzed surface samples taken at 168 locations for physical characteristics which index erodibility of the soil. The samples were selected in the major soil-geologic types of California, under standard conditions of slope, elevation, vegetation types and in three separate zones. A multiple regression analysis related the surface-aggregation and dispersion ratios, as indices of erodibility, to geologic type, vegetation type, zone, and elevation, and to their interactions. The surface-aggregation ratio was found to be somewhat more significantly related to soil erodibility than was the dispersion ratio. Soil developed from acid igneous rock was about 2-1/2 times as erodible as soil developed on basalt. The interaction of zone and geologic rock type showed significant variation in erodibility. Andre and Anderson's prediction equation explained 52 percent of the variability in erodibility in soils. By combining predicted erodibility from the equation with chemical base status the explained variance was improved.

At the completion of their study, Andre and Anderson concluded that both soil erodibility indices were significantly related to soil-geologic rock type and that the surface-aggregation ratio is also related to vegetation and geographic zone in Northern California. They stated that partial regression coefficients can be directly compared to one another or used singly in any combination desired to predict soil erodibility. They further stated that when soil erodibility is considered with other factors in erosion--the intensity and frequency of rainfall, and land use and condition, for example--then erosion may be predicted and erosion hazard assigned to land areas.

This literature search has been conducted with the principal objective of orienting personnel involved in the research project to the varied aspects of erosion. In 1952-53 a study was conducted at this laboratory to evaluate the efficiency of chemical coatings on highway slopes as an erosion deterrent. Since that time no research work in the field of erosion has been undertaken by this department. Readings of texts, journals, periodicals, etc., provided basic indoctrination on the nature of erosion; its causes; remedial measures; and particularly, methods for the prediction of potential erosivity of soils.

The search indicated that the preponderance of past research on erosion has applications primarily to streambed banks and to extended open areas such as agricultural lands and watersheds. Comparatively little data related to the specific area of man-made slopes as encountered in highway construction was found. One of the prime objectives of this research project will, therefore, be to determine the feasibility of adapting the erosion control technology developed for the broad areas involving natural slopes to the more restricted parameters within which the highway designer must function.

A major factor in erosion prediction is a soils inherent erodibility, a complex property dependent on its infiltration capacity and on its capacity to resist detachment and transport by rainfall and runoff. It was considered desirable to explore these soil properties as a first line of work and the laboratory test program conducted during this phase was oriented to this end.

IV. LABORATORY TESTS

The laboratory work undertaken during Phase I of the project involved two important indices of soil properties generally accepted by authorities to be key factors in determination of potential erosivity. These indices are the dispersion ratio of Middleton and the surface aggregation ratio as developed by H. W. Anderson.

Middleton's dispersion ratio

The dispersion ratio provides an index of the ease with which the silt-clay fraction of a soil will disperse when agitated in pure water. It is a logical index since it can be inferred that material easily brought into suspension will be quickly washed away, or eroded.

Middleton's dispersion ratio (U.S.D.A. Tech. Bull. 178, March, 1930) is determined as follows: 10 grams of air-dry soil is hand-shaken in sufficient distilled water to make a total volume of one liter. The suspension is allowed to settle until a 25 cubic centimeter sample, pipetted at a depth of 30 centimeters, consists of particles of a maximum diameter of 0.05 millimeters. From the dry weight of the pipetted fraction, the total weight of silt and clay in the suspension is calculated. The ratio of the silt and clay so determined to the total, or ultimate, silt and clay in the sample, as determined by mechanical analysis utilizing a dispersing agent, is called the dispersion ratio.

The surface-aggregation ratio is calculated from the dispersion ratio data and surface area factors assigned to soil particles greater than 50 microns in diameter. This ratio as an index represents the amount of soil surface requiring binding to the amount of binding clays present in the soil.

Limitations on the scope of soil testing activities during Phase I precluded the procurement and processing of samples from the field specifically for this program. It was found expedient to carry out the test trials utilizing portions of "basement soil" samples originally taken for "R" value determinations. These surface soils had been subjected to routine processing and classification tests prior to their acquisition for our use. A total of 14 samples, comprising two groups, were tested. Group No. 1 consisted of eight samples of a relatively uniform soil type from a source near Tracy. A second group of six samples represented diverse sources and a wider range of soil types.

Dispersion ratios for the Tracy soils (Group No. 1) were obtained in adherence to Middleton's procedure. A metal tip was constructed for the end of the pipette with six radial No. 80 drill holes as specified. Following agitation of the combined soil plus water, a settlement period of 60 seconds was permitted prior to pipettement of the suspension. This one minute interval was determined by experimentation. Four tests were conducted on each of the eight samples in this group to check on the reproducibility of results. Some difficulty was experienced in obtaining four 10 gram increments of like composition from the base samples due to broad ranges in particle size. The erratic results obtained from several tests are believed attributable to non-uniformity of sample increments, however, this was not proven. The second factor in the dispersion ratio calculation, the total (or ultimate) silt plus clay was determined by our standard mechanical analysis procedure (Test Method No. Calif. 203-C).

The dispersion ratio and surface aggregation ratio data from the Tracy soils are depicted on Table 1. Here, reproducibility of "dispersion ratio" values appear reasonable as indicated by probable error and range. This was not the case with respect to "surface aggregation ratio", however, where two of the eight samples had ranges in excess of the mean test values.

Based upon the advice of Mr. H. W. Anderson[1-4] it was decided to conduct subsequent dispersion ratio tests in conformance with Anderson's modification of the Middleton method, as follows: the soil sample increment was increased to 50 grams in weight and the suspension percent was measured with a hydrometer following a settlement period of 40 seconds. This modification simplifies and expedites determination of the suspension percentage through elimination of the drying requirements. Further, a 50 gram increment of soil is undoubtedly a more representative sample than the previously used 10 grams. The ultimate silt and clay fraction of the soil is dispersed by soaking the sample in a Calgon-water solution for an appropriate period; followed by machine stirring, hand throws, and hydrometer readings.

Dispersion ratios utilizing the above procedure and surface-aggregation ratios were conducted on a second group of six samples listed as Group 2. Test data from this series is shown on Table 2. A comparison of values resulting from the two suspension times utilized (40 and 60 seconds) indicated a considerable improvement in reproducibility.

As field conditions in the various areas represented by the samples tested is not known, correlation of the data with the current state of erosion was not possible, and its validity is, therefore, conjectural. These data are further prejudiced by the fact that the samples as used, were improperly processed for use in determinations of erodibility factors. It is now realized that the integrity of the soil structure must be respected during the pre-test handling of the sample. Such samples should be carefully air dried to a friable consistency and the peds gently broken by hand before passing the soil through a 2 mm sieve. Since the samples used in our laboratory tests had been subjected to routine processing which entails rigorous reduction of the peds to primary aggregates the test values probably do not accurately represent the erodibility potential of the soils.

TABLE 1

Sample No.	Dispersion Ratio	Mean	Range	Standard Deviation	Probable Error	Surface Aggregation Ratio	Mean	Range	Standard Deviation	Probable Error
1059	87.2 80.0 96.7 70.4	83.58	26.3	11.13	7.51	29.6 19.0 116.0 13.0	44.4	103.0	45.35	30.59
1060	69.4 70.4 70.4 67.3	69.38	3.1	1.46	0.98	12.1 12.5 12.5 11.3	12.1	1.2	0.57	0.38
1061	95.2 95.2 86.9 77.4	88.68	17.8	8.47	5.71	83.0 83.0 30.0 17.5	53.4	65.5	34.59	23.33
1062	62.9 70.2 71.1 64.5	67.18	8.2	4.08	2.75	9.9 12.3 12.7 10.3	11.3	2.8	1.40	0.94
1063	87.5 75.6 80.7 69.6	78.35	17.9	7.60	5.13	29.7 15.2 19.2 12.2	19.1	17.5	7.64	5.15
1064	84.2 70.2 80.7 83.0	79.52	14.0	6.38	4.30	24.4 12.9 20.0 22.8	20.03	11.5	5.09	3.43
1065	83.7 87.0 85.9 75.0	82.90	12.0	5.44	3.67	23.4 29.2 27.0 15.3	23.7	13.9	6.10	4.11
1066	77.8 78.7 86.9 78.7	80.53	9.1	4.27	2.88	17.5 18.2 29.5 18.2	20.9	12.3	5.78	3.90

TABLE 2

DISPERSION RATIO AND SURFACE AGGREGATION RATIO SUMMARY

Sample No.	Grain Size (in percent) Class.				Elapsed Suspension Time	Sus-pension* Percent	Ult. Silt** Clay%	Dis-persion Ratio	Surface Aggr. Ratio
	>2 mm (Gravel)	2.0 - .05mm (Sand)	.05 - .005mm (Silt)	<.005mm (Clay)					
70-1001-1	3	1	35	61	40 sec	48	97.2	49.4	4.9
70-1001-2					60 sec	46	95.2	48.3	4.9
70-1067-1	35	30	18	17	40 sec	38	43.2	88.0	35.4
70-1067-2					60 sec	34	41.2	82.5	25.6
70-1094-1	3	38	47	12	40 sec	40	45.2	88.5	47.1
70-1094-2					60 sec	34	39.2	86.7	47.1
70-1095-1	2	57	26	15	40 sec	30	37.2	80.6	24.7
70-1095-2					60 sec	28	35.2	79.5	24.7
70-1107-1	20	25	30	25	40 sec	52	63.2	82.3	20.3
70-1107-2					60 sec	46	57.2	80.4	20.3
70-1109-1	20	33	28	19	40 sec	42	53.2	78.9	19.4
70-1109-2					60 sec	38	47.2	80.5	23.6

* 50 grams soil plus distilled water to make 1000 cc, hand thrown 20 times.

** 50 grams soil plus 5 g. Calgon plus distilled water to make 1000 cc, soaked for 110 hours, mixed mechanically for 1 minute, hand thrown 20 times.

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